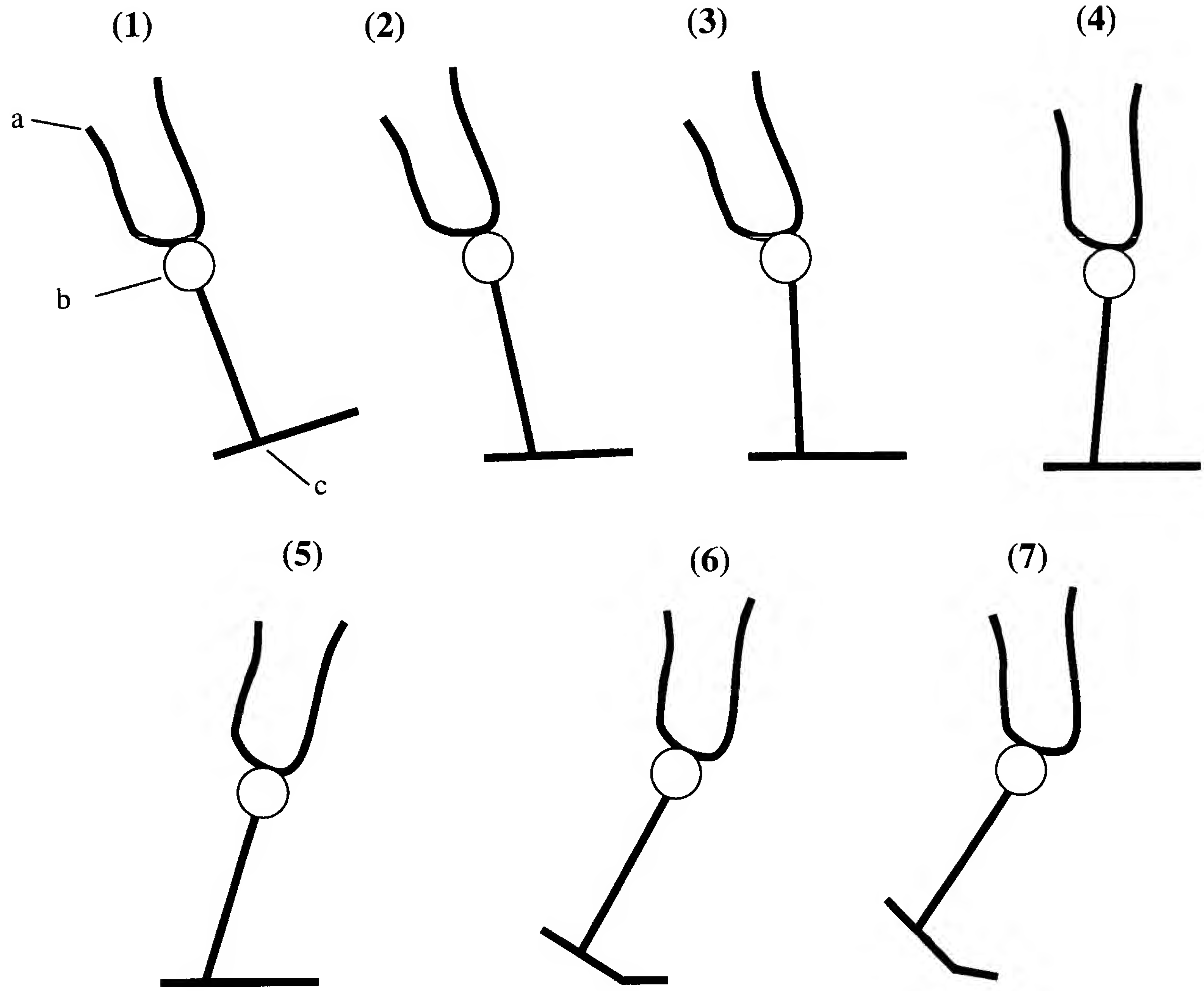

Figure 1: An external prosthesis, robotic limb, or orthotic brace is shown in a heel strike to toe-off walking sequence. The system comprises above-knee segment (a), knee joint (b), and ankle joint (c).

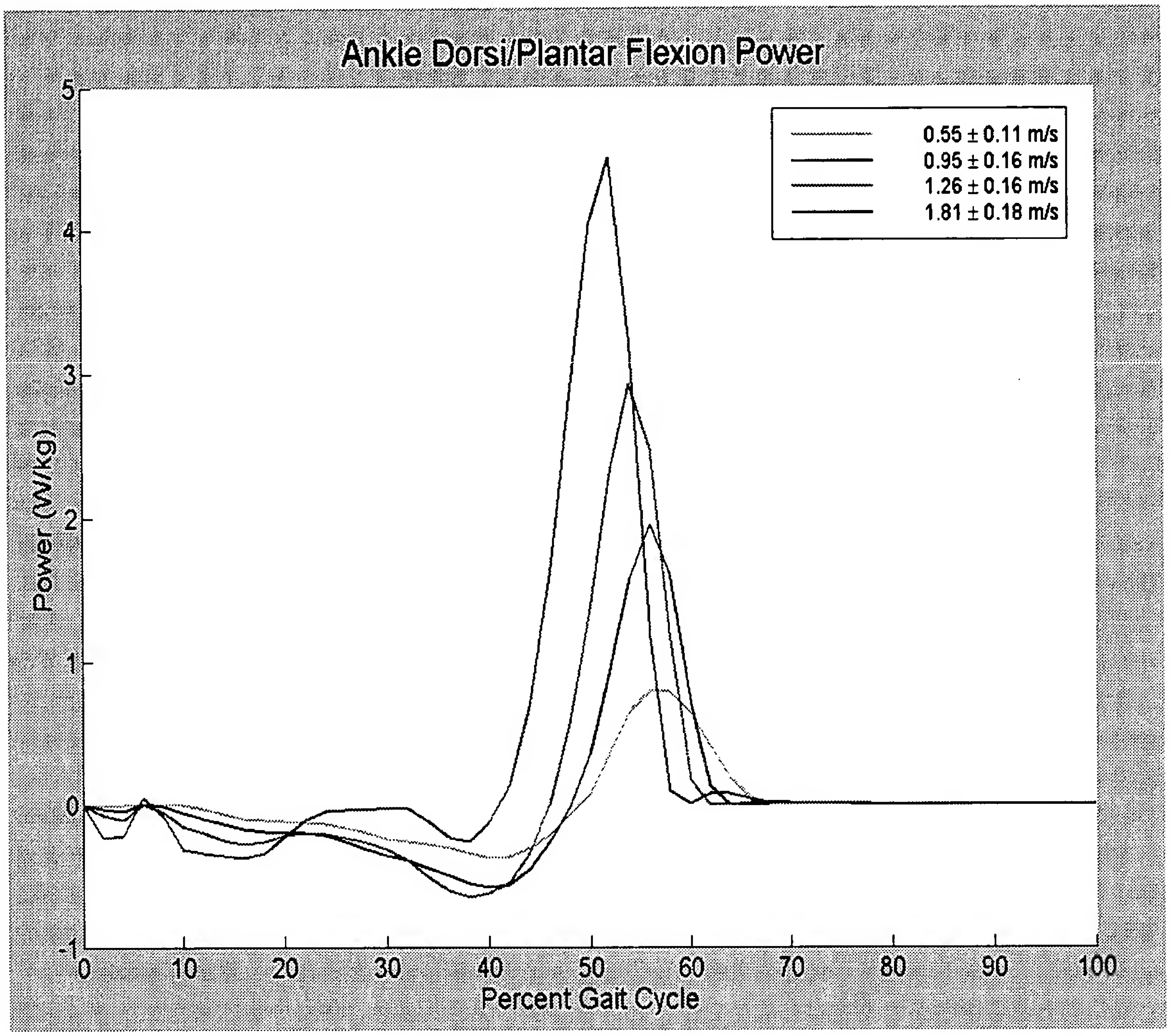

Figure 2: Data from ten normal subjects are plotted showing mechanical power output versus percent gait cycle in walking. Both zero and one hundred percent gait cycle correspond to heel strike of the same foot. On the vertical axis, mechanical power output is normalized by total body mass. Each curve represents a different walking speed from slow walking (0.5 m/sec) to fast walking (1.8 m/sec). As walking speed increases, both peak power and total positive work from the ankle increases, demonstrating the thrusting nature of normal ankle function. Data taken with permission from Spaulding Gait Laboratory, Spaulding Rehabilitation Hospital, Boston, MA.

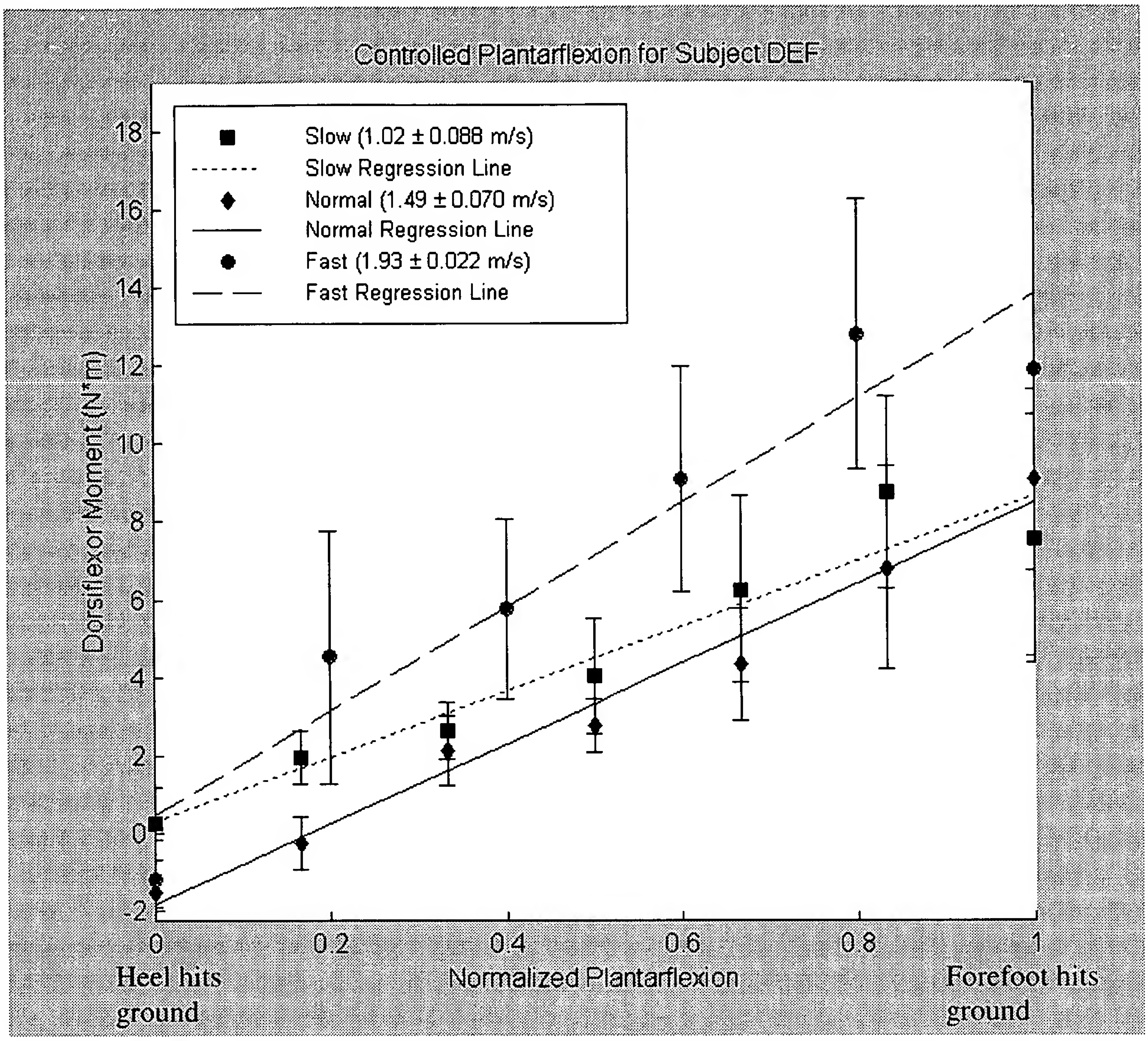

Figure 3: Data for one subject are plotted showing normal biological ankle function during the controlled plantar-flexion phase of walking. Three walking speeds are shown: squares for the slowest speed, triangles for the subject's self-selected walking speed, and circles for the fastest speed. The horizontal axis is normalized to the maximum plantar-flexion angle where the forefoot first makes contact with the walking surface. A normalized plantar-flexion angle of zero occurs where the ankle first begins to plantar-flex just after heel-strike. Ankle stiffness, or the slope of each linear regression, increases by 40% from slow walking (k = 1 kN/m) to fast walking, (k = 2 kN/m). Data taken with permission from Spaulding Gait Laboratory, Spaulding Rehabilitation Hospital, Boston, MA.

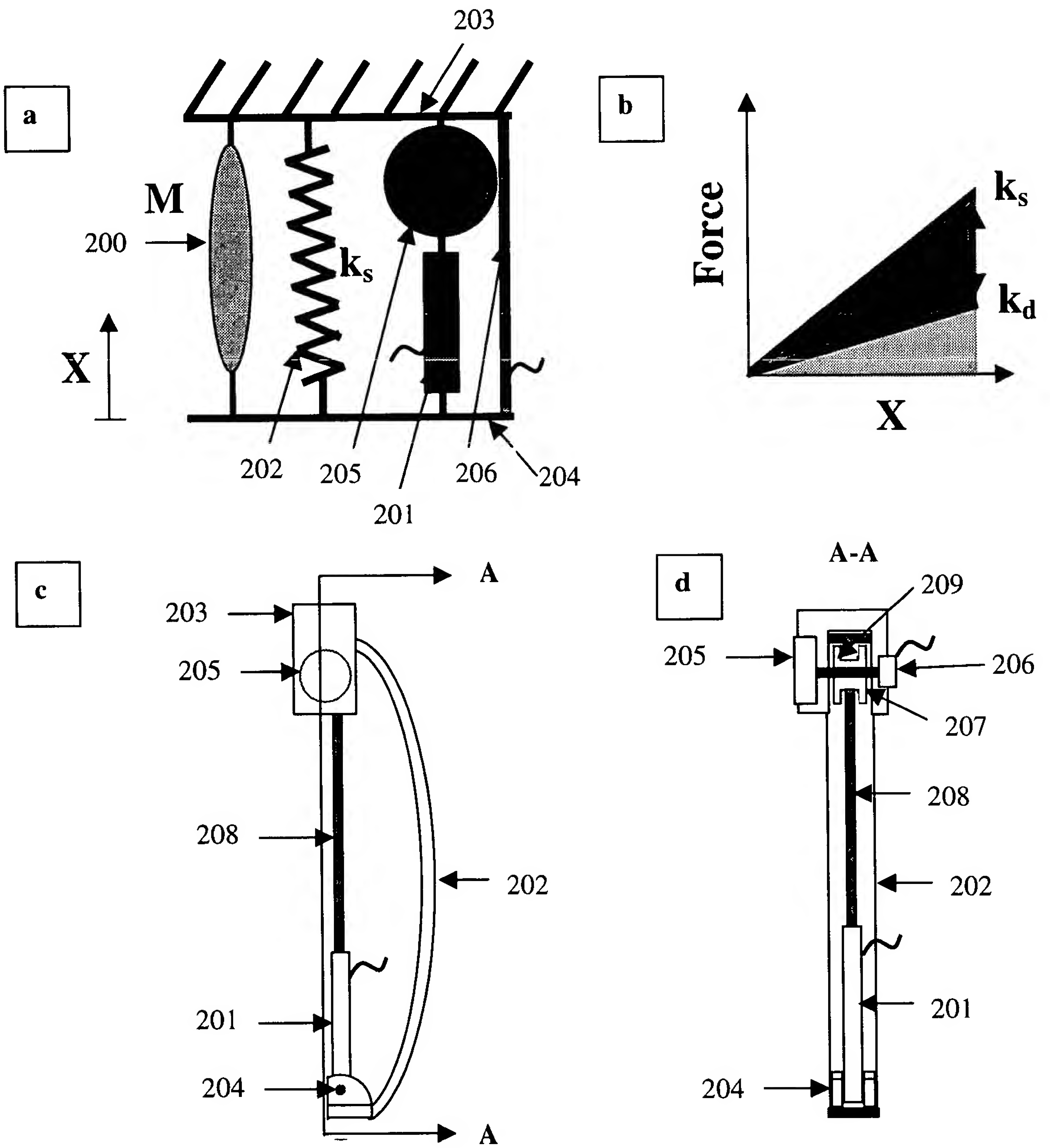

Figure 4: Prosthetic mechanisms designed to power plantar-flex are shown. Mechanism (a) lumped-element model, (b) force-displacement diagram showing positive power area, (c) side-view example of powered catapult prosthetic, (d) front view example of powered catapult prosthetic.

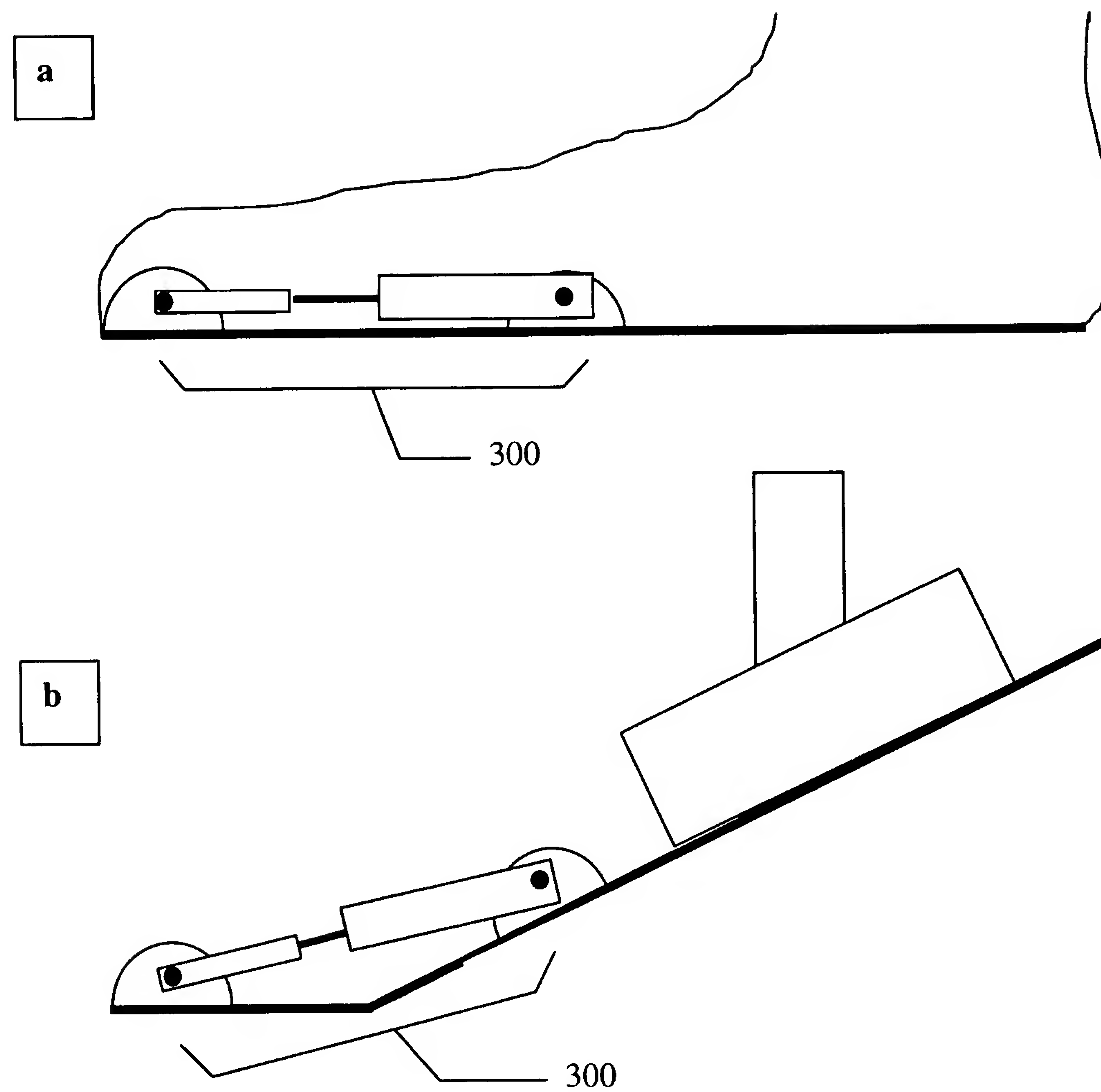

Figure 5: Catapult leg prosthesis for walking, running, and jumping. In a), the equilibrium configuration of the catapult spring 300 is shown. In b), the catapult spring 300 in a compressed state.

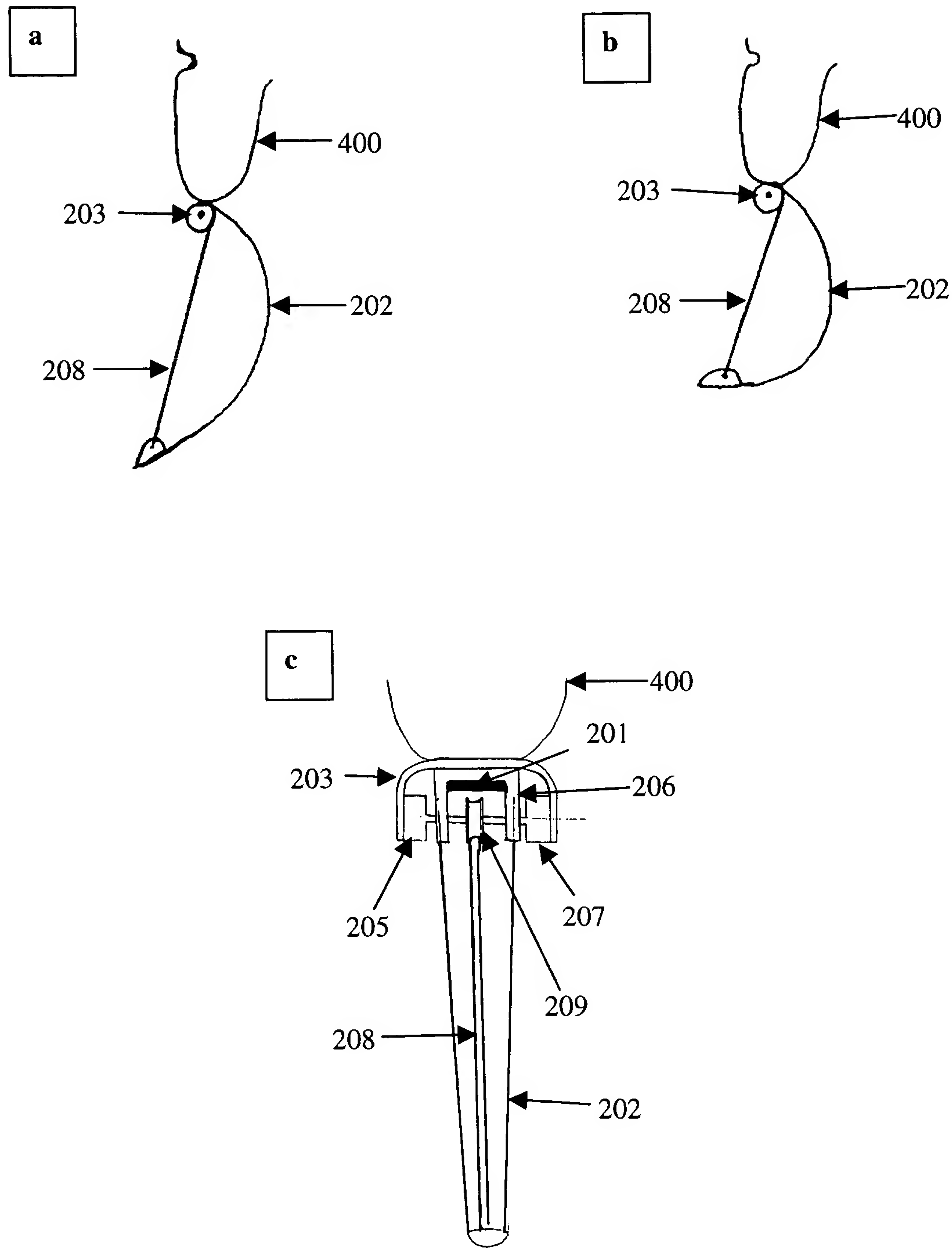

Figure 6: Catapult leg prosthesis for walking, running, and jumping. In a), the equilibrium configuration of the catapult spring 202 is shown. In b), the catapult spring 202 in a compressed state. In c), the mechanism for storing and then releasing spring energy is shown including motor 205, spool 209, and clutch 207.

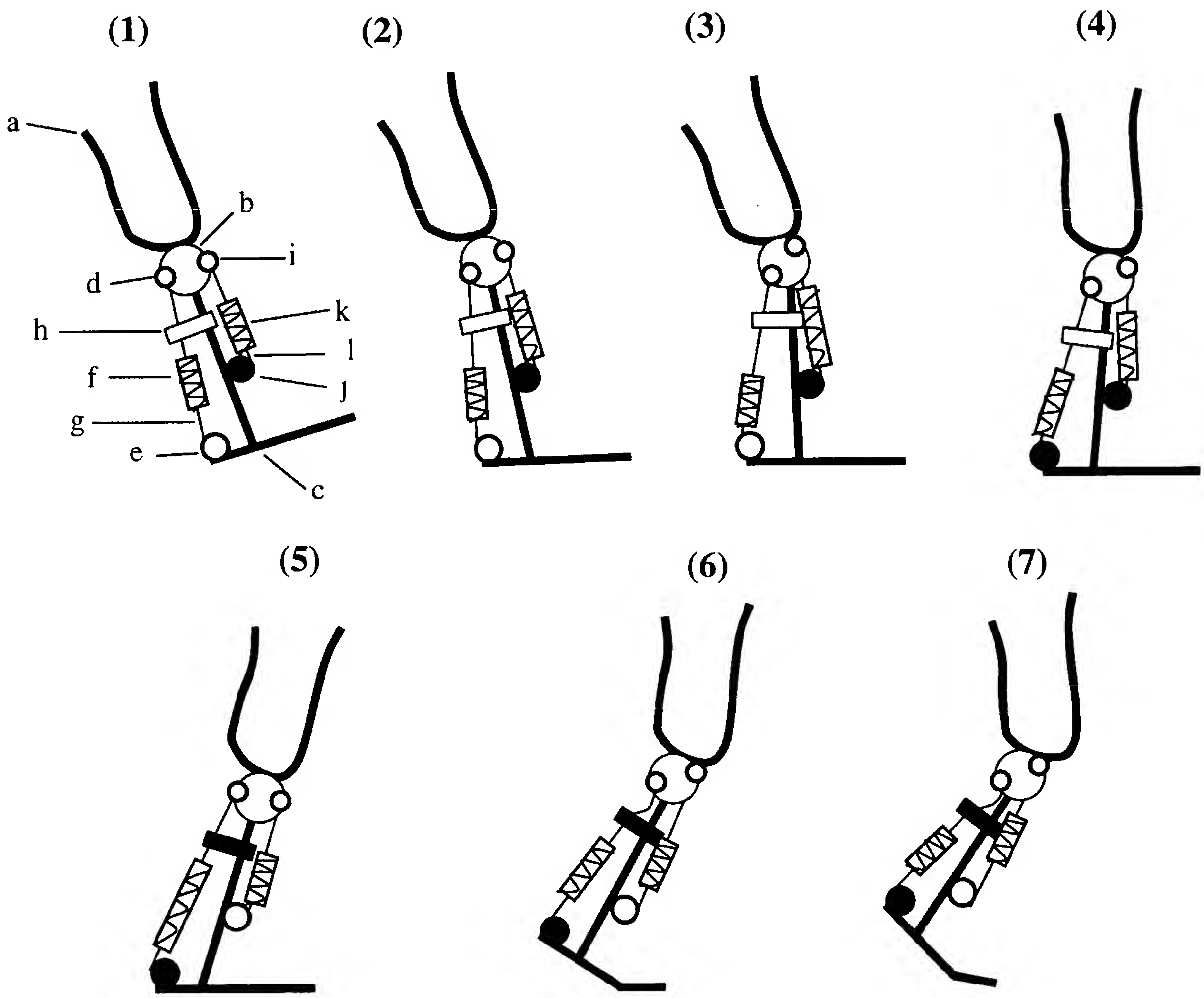

Figure 7: An external, bi-articular transfemoral prosthesis, robotic limb, or orthotic brace is shown in a heel strike to toe-off walking sequence. The system comprises above-knee segment (a), knee joint (b), ankle joint (c), posterior knee pivot (d), posterior clutch (e), posterior spring (f), posterior cord (g), knee-ankle transfer clutch (h), anterior pivot (i), anterior clutch (j), anterior spring (k), and anterior cord (l). The system of springs and clutches allows for normal knee and ankle motions throughout the stance period of walking, including early stance knee flexion (1 to 3) and ankle controlled plantar-flexion (1 to 2), controlled dorsi-flexion (2 to 5) and powered plantar flexion (5 to 7). For posterior and anterior clutches (e, j), and knee-ankle transfer clutch (h), the clutch state is designated by an open or closed symbol. Closed symbols represent an engaged or locked clutch state, while open symbols represent a disengaged or unlocked state. For example, during late stance knee flexion (sequence 6 to 7), anterior clutch (j) is in the disengaged state and therefore is designated by with an open symbol.

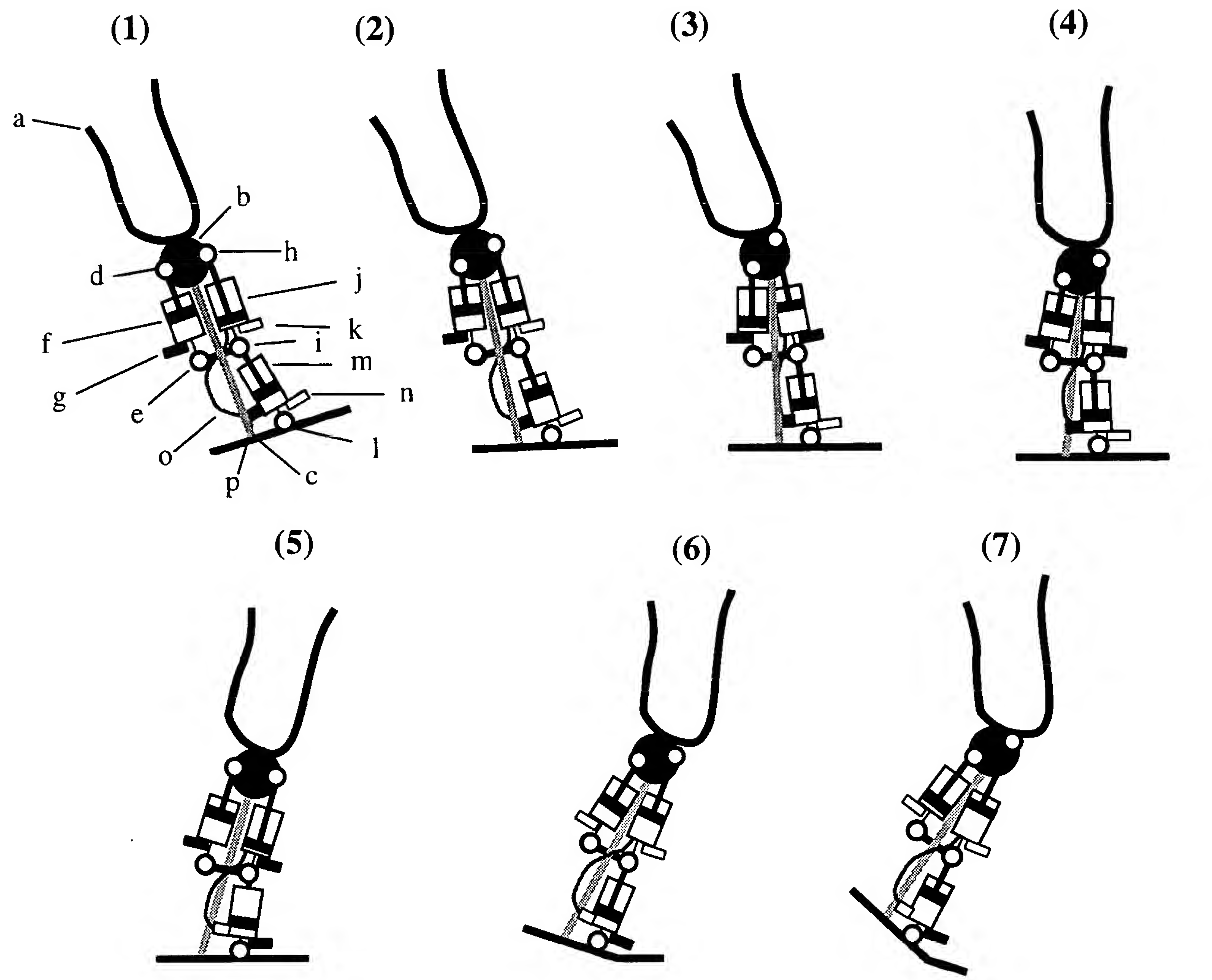

Figure 8: An external, bi-articular transfemoral prosthesis is shown in a heel strike to toe-off walking sequence. The prosthesis comprises above-knee socket (a), knee joint (b), ankle joint (c), posterior knee pivot (d), posterior shank pivot (e), posterior pneumatic spring (f), posterior knee valve (g), anterior knee pivot (h), anterior shank pivot (i), anterior pneumatic spring (j), anterior knee valve (k), foot pivot (l), ankle pneumatic spring (m), anterior ankle valve (n), knee-ankle transfer tube (o), and knee-ankle transfer valve (p). The system of pneumatic springs and valves allows for normal knee and ankle motions throughout the stance period of walking, including early stance knee flexion (1 to 3) and ankle controlled plantar-flexion (1 to 2), controlled dorsi-flexion (2 to 5) and powered plantar flexion (5 to 7). For posterior and anterior knee valves (g, k), anterior ankle valve (n), and knee-ankle transfer valve (p), the valve state is designated by an open or closed symbol. Closed symbols represent a closed valve state, while open symbols represent an open valve.

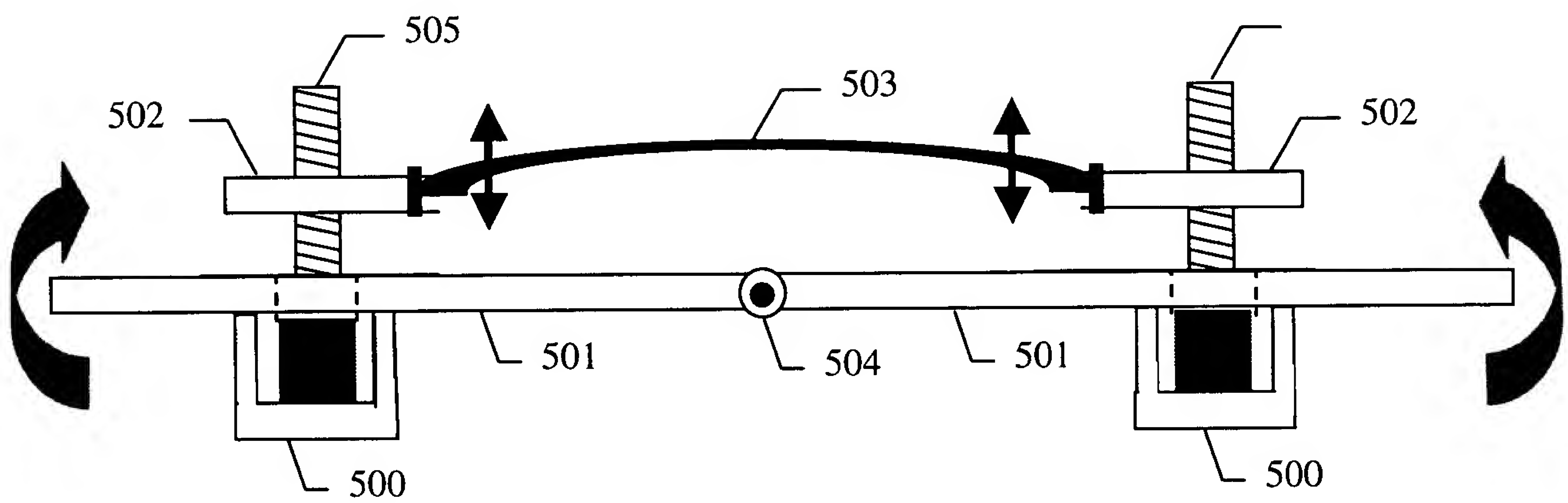

Figure 9: Variable spring-rate joint

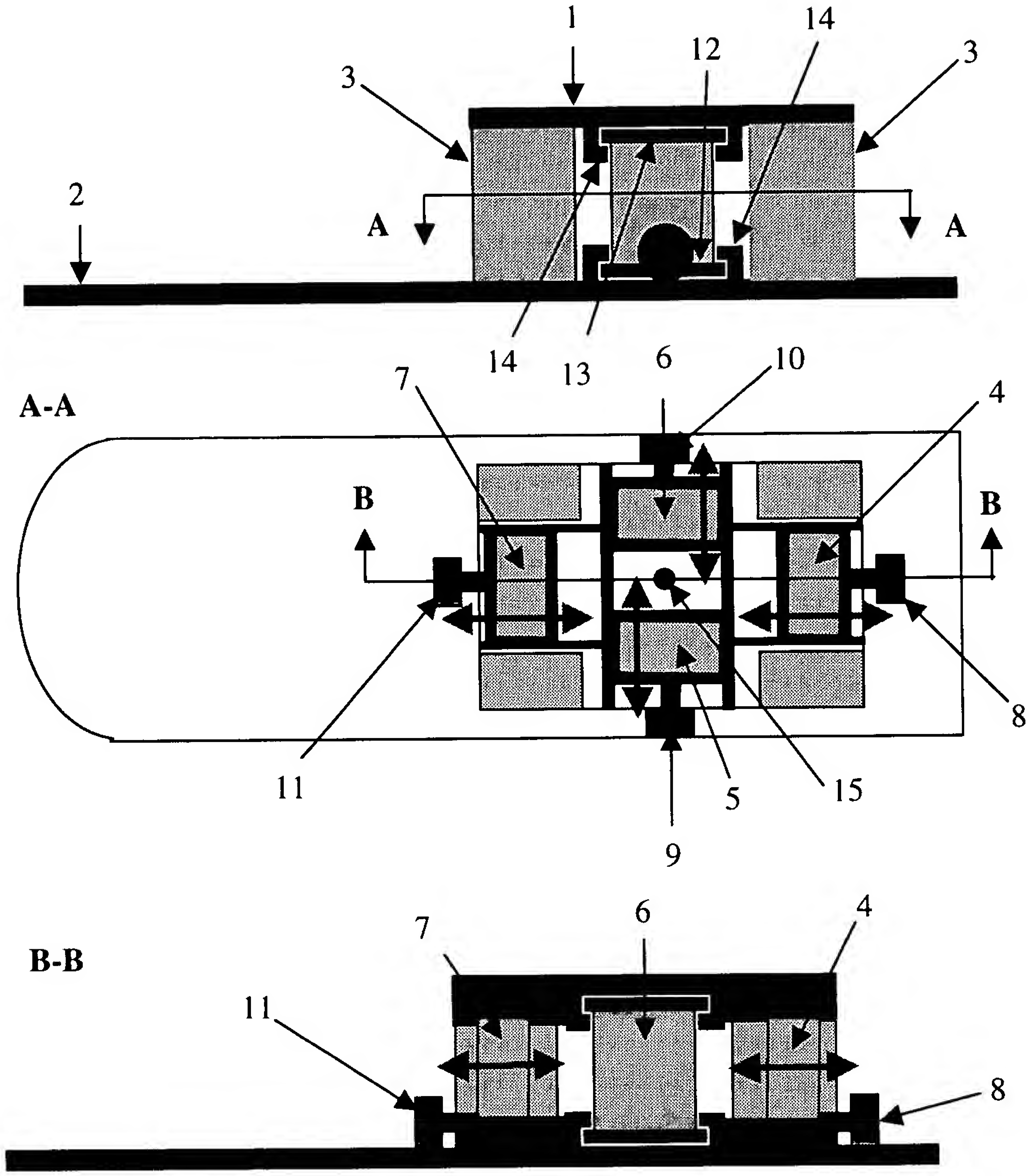

Figure 10: A low-profile prosthetic foot is shown where spring elements are actively controlled to affect ankle-joint stiffness. Here motors 8, 9, 10, and 11 are employed to control the location of four spring elements 4, 5, 6, and 7 relative to ankle plate 1. Such a mechanism offers independent inversion/eversion stiffness control as well as independent plantar and dorsi-flexion control.

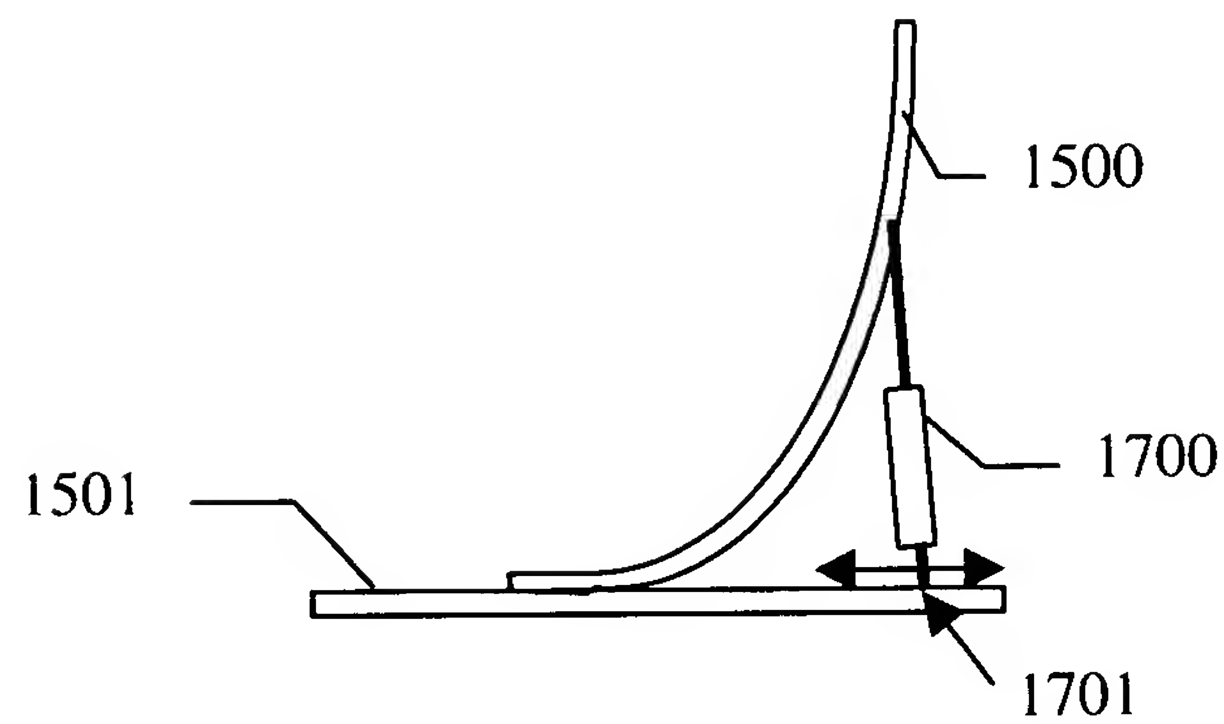

Figure 11. Example prosthetic ankle/foot utilizing constant spring or damping element 1700, and controllable variable attaching point 1701 to produce variable mechanical advantage and thus variable spring rate or damping rate.

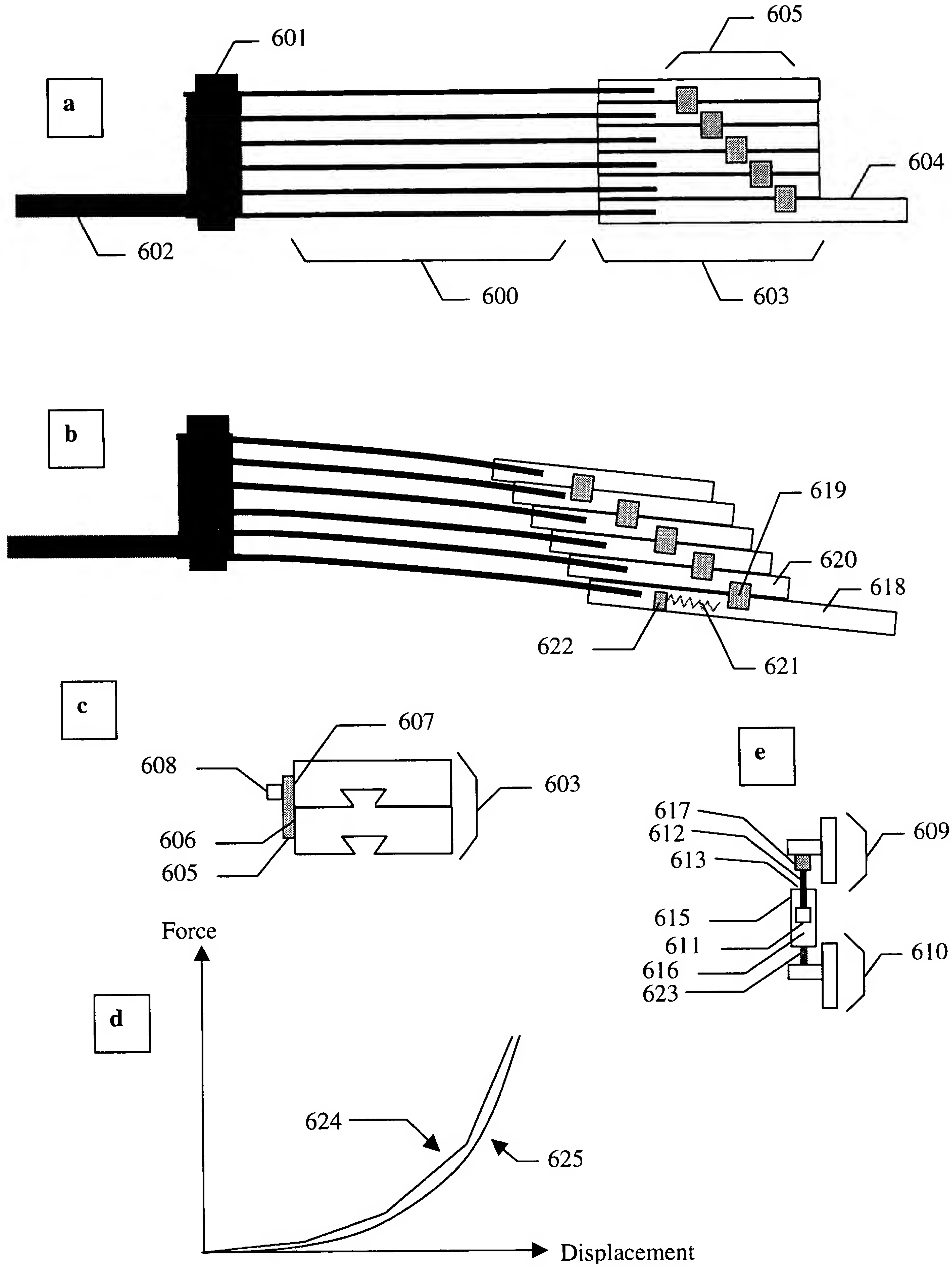

Fig 12. Multiple-layer leaf spring (a,b) with dynamically interlockable layers (c) gives a piecewise-linear spring function (d) resulting from a controlled coupling of elements of multiple-parallel-element spring.

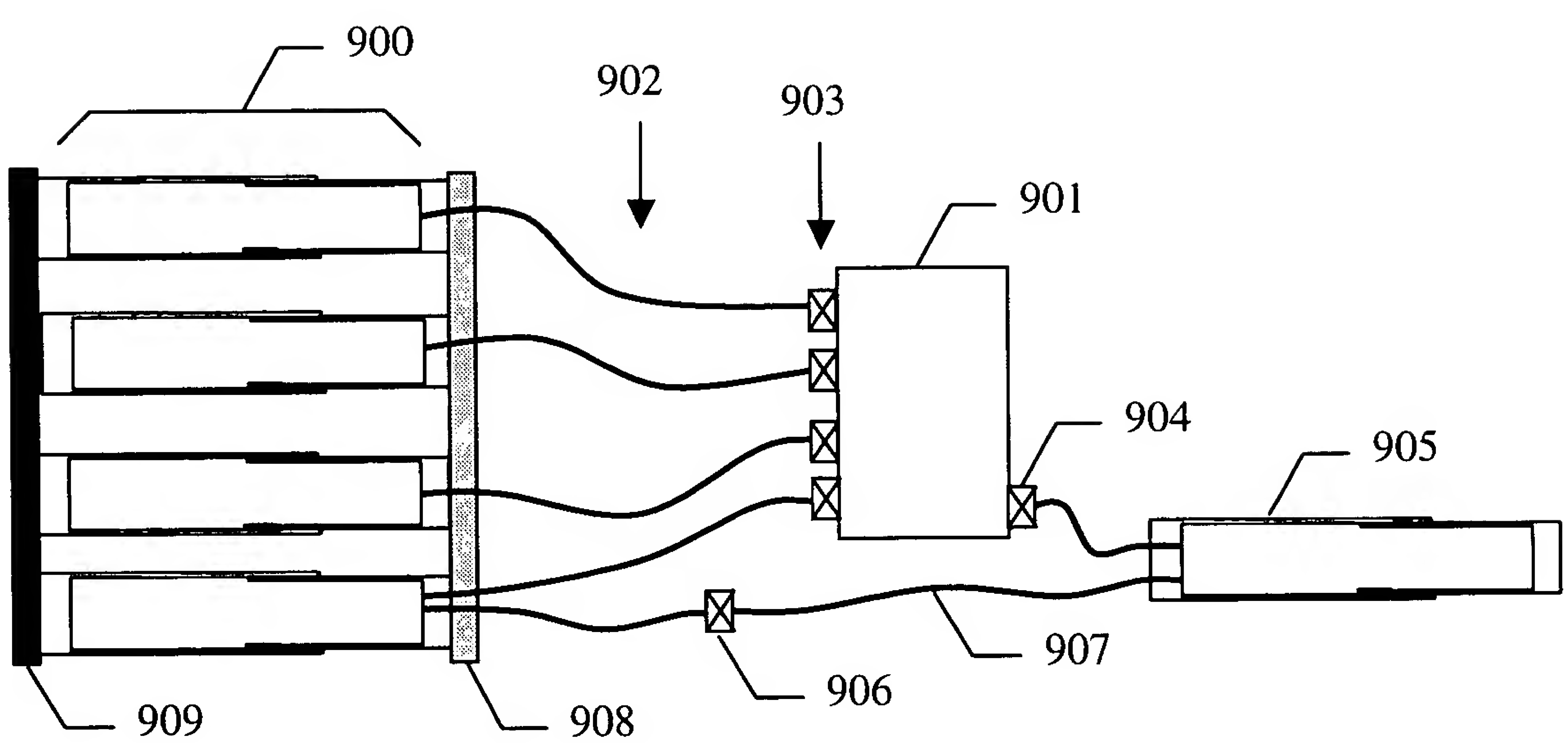

Fig 13. Multiple-pneumatic-chamber variable spring rate and energy-transferring system.

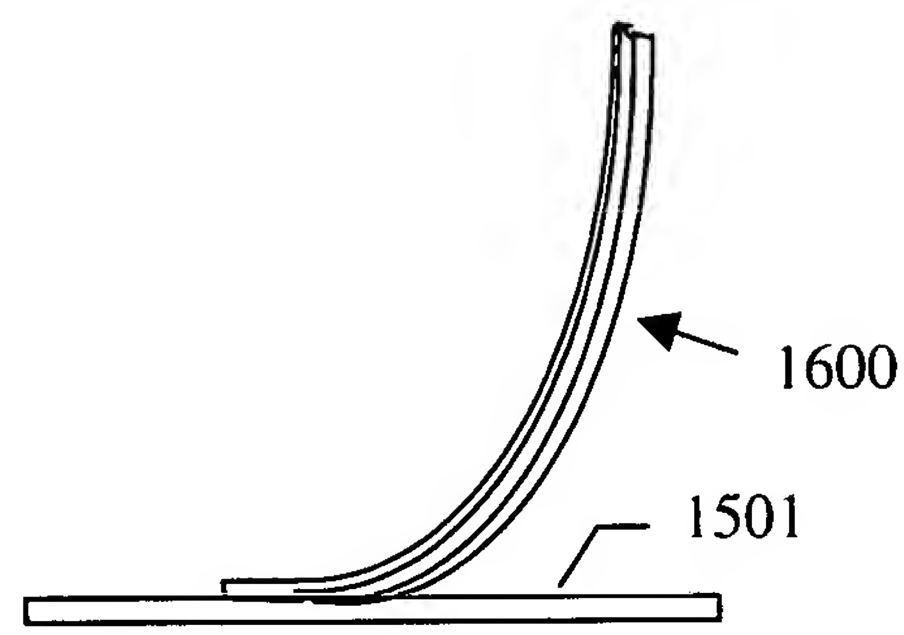

Figure 14. Prosthetic ankle-foot utilizing multiple interlockable parallel leaf springs for ankle spring 1600.

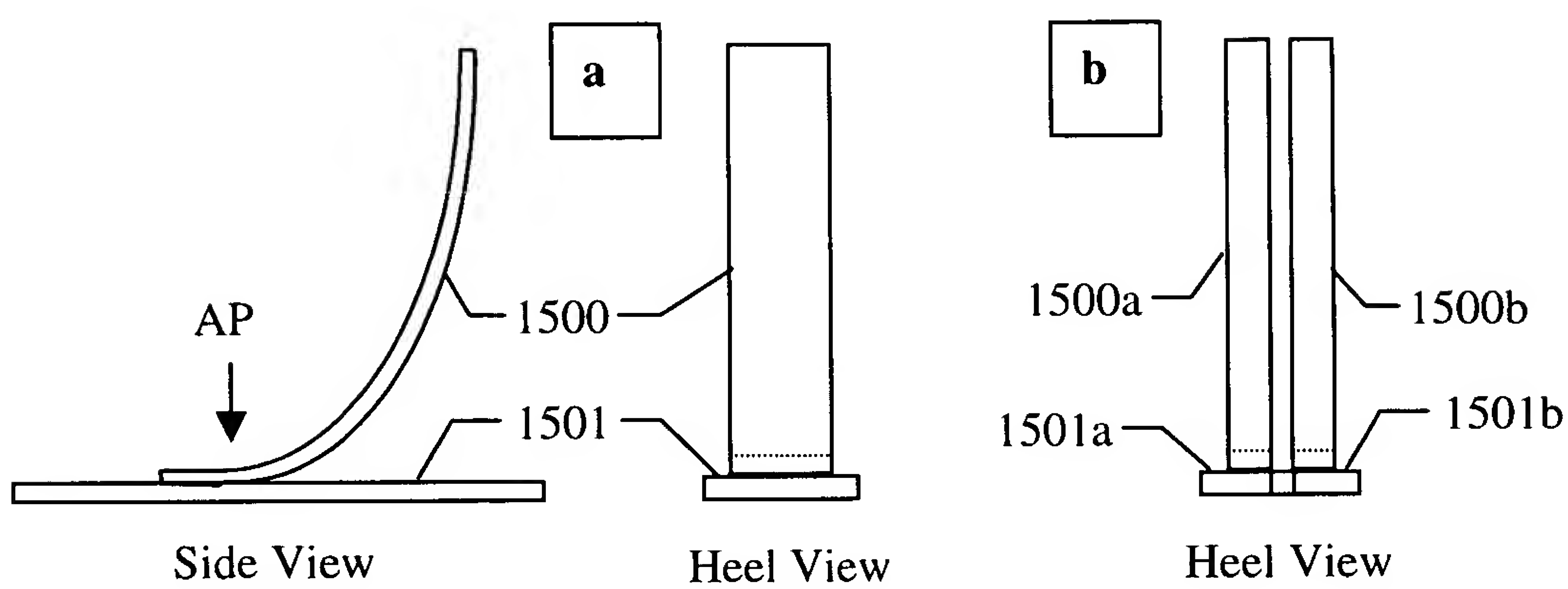

Figure 15. Example prosthetic ankle-foot known in the art, showing ankle spring 1500 and heel spring 1501, and improved prosthetic foot according to the present invention.

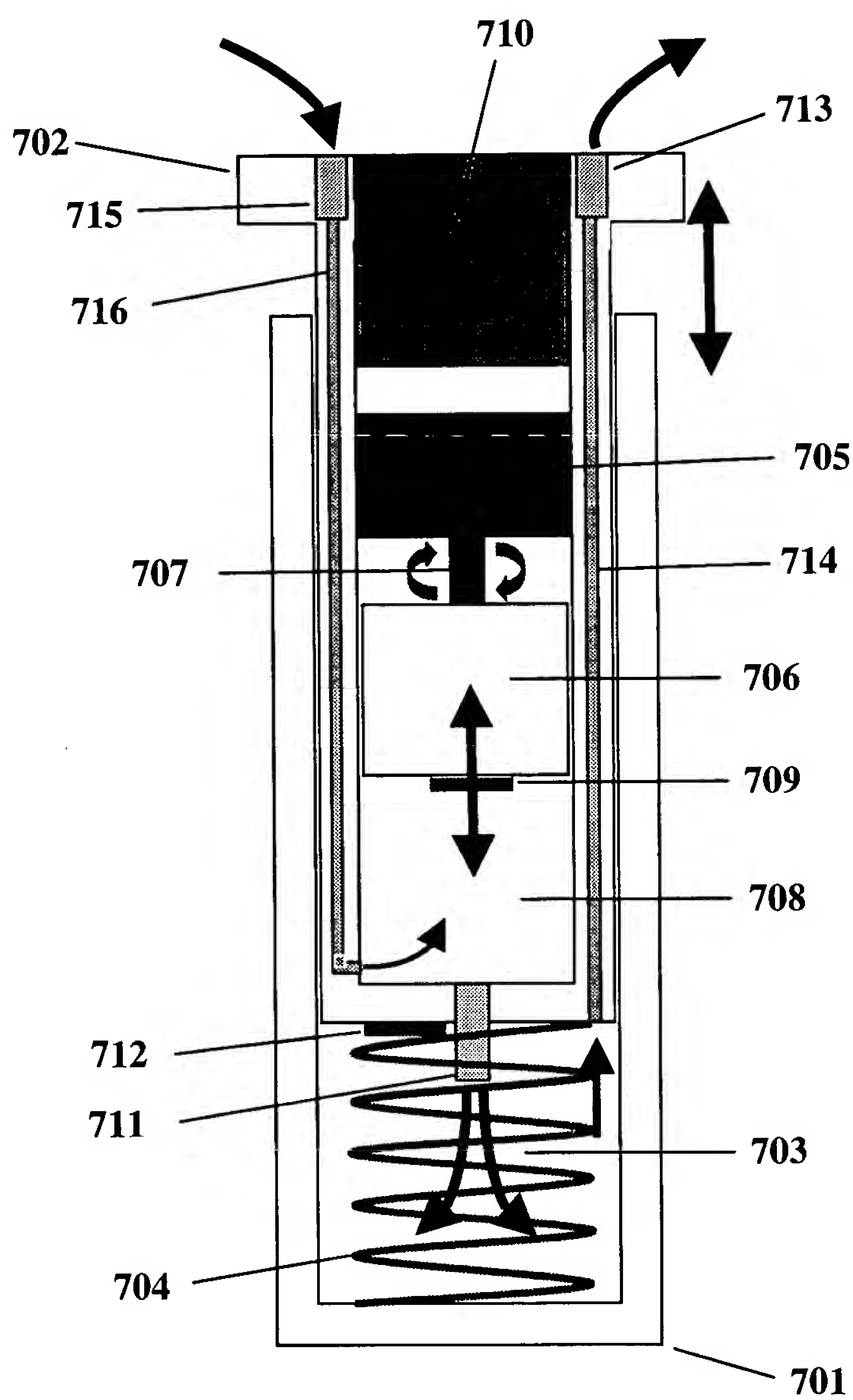

Figure 16. A variable stiffness spring is shown for an external prosthesis, robotic limb, or orthotic brace. The system comprises female segment (701), male segment (702), spring chamber (703), chamber spring (704), motor (705), piston (706), ball screw (707), compressed air chamber (708), storage pressure sensor (709), power supply, microprocessor and electronics (710), pressure increase valve (711), spring pressure sensor (712), pressure release valve (713), pressure release channel (714), air intake valve (715), and air intake channel (716).